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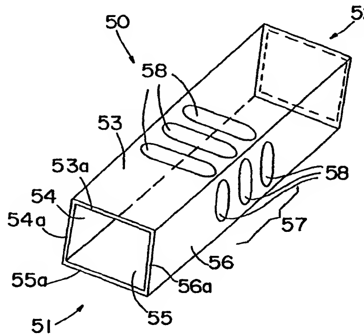
(54) Title: CONTROLLED DEFORMABILITY OF ALUMINUM, OR OTHER METAL STRUCTURE

(57) Abstract

A controllably deformable frame structure comprising a structural member (50) and a member for controllably deforming the frame structure. The controllably deforming structure comprises at least one energy-absorbing zone (57) disposed within the structural member. In turn, the structural member will deform controllably when subjected to loads of lesser magnitude than required to plastically deform the remainder of the at least one structural member. The invention likewise comprises a method of manufacturing a frame structure.



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TITLE OF THE INVENTION

Controlled Deformability of Aluminum, or Other Metal Structure

BACKGROUND OF THE INVENTION

1. The Technical Field

The present invention relates in general to frame structures. In particular, the present invention relates to aluminum and other metal frame structures which are capable of bearing substantial static and dynamic structural loads, yet which are controllably deformable in the event they are subjected to loads of greater than a predetermined value.

2. The Prior Art

Aluminum and other metal frame structures have been known in the art for many years. Such frame structures have long been used in the design of storage racks, containers, and other applications. In particular, such frame structures have been extensively used in the production of vehicles, such as aircraft, automobiles, and trucks, where it is particularly desirable to provide a frame structure which is sturdy, uses materials efficiently so as to be relatively lightweight and inexpensive, and is commercially practical to produce. In addition to exhibiting these qualities, vehicle frame structures are typically designed to deform when subjected to loads, particularly compressive and bending loads resulting from a collision with another vehicle or a stationary object, which exceed predetermined structural design limits. By deforming when subjected to such loads, the frame structure can absorb a significant amount of the collision impact energy which would otherwise be

transmitted to the passenger cell, thus preventing many potentially serious injuries to the vehicle's occupants.

In the past, it has been standard automotive industry practice to insert certain components into a vehicle structure specifically so that they will preferentially deform during a collision. In this manner, designers have been able to design collision energy management into a vehicle structure. However, in the past, vehicle designers have generally been limited to using conventional structural materials. Although the properties of such materials are well-known and well-documented, it is difficult to design a frame structure using such materials that is sturdy enough to support the requisite structural loads, yet capable of absorbing a sufficient amount of collision energy to protect the vehicle's occupants after an accident, without adversely affecting the structure's weight, cost, and ease of production.

Retrogression heat treatment (RHT) technology, as disclosed by Benedyk, U.S. Pat. No. 5,458,393, has been used in the past to reduce the number of elements and discontinuities in a vehicle structure. Benedyk discloses a space frame and manufacturing method involving the use of induction heating to locally soften distinct points on vehicle frame components, thus significantly increasing the formability of the metal. The locally softened areas are then worked, formed, and assembled, as desired. After these operations have been completed, the effected areas are generally hardened towards their pre-softened hardness. The apparatus and method of Benedyk yield an efficiently assembled frame structure which is comprised of relatively fewer components than a conventional frame structure, yet

which exhibits structural characteristics which are comparable or superior to those of a conventional structure.

Accordingly, it is an object of the present invention to use localized induction heating technology to locally soften certain locations on aluminum and other metal structures to establish a pattern or pre-softened "trigger points" that constitute one or more energy absorbing zones within the overall structure. It is also an object of the present invention to use localized induction heating technology to soften certain locations on aluminum and other metal structures to enable establishment of a predetermined pattern of pre-buckled "trigger points" that constitute one or more energy absorbing zones within the overall structure. It is further an object of the present invention to orient such trigger points in a manner that allows for controlled deformation of the energy absorbing zone after an impact.

These and other objects of the present invention will become apparent in light of the present specification, claims, and drawings.

SUMMARY OF THE INVENTION

The invention comprises a controllably deformable frame structure comprising at least one structural member and means for controllably deforming the frame structure. The controllable deforming means comprises at least one energy absorbing zone operably disposed within at least one of the at least one structural member to, in turn, controllably deform when subjected to loads of lesser magnitude than required to plastically deform the remainder of the at least one structural member.

In a preferred embodiment, the at least one structural member comprises a metal material. In such an embodiment, the metal material may comprise aluminum.

In another preferred embodiment, the at least one structural member comprises an extruded member. In another preferred embodiment, the at least one structural member comprises a stamped member.

Preferably, the frame structure comprises at least a portion of an automobile frame structure. In such an embodiment, the automobile frame structure may comprise a bumper support.

In yet another preferred embodiment, the at least one energy absorbing zone of the at least one structural member comprises a locally heat treated region. In another preferred embodiment, the at least one energy absorbing zone of the at least one structural member comprises at least one of a mechanically pre-deformed region and a locally heat treated region.

In another preferred embodiment, the at least one energy absorbing zone of the at least one structural member comprises a region which has been locally heat treated, mechanically pre-deformed, and rehardened.

The invention further comprises the method for manufacturing a frame structure which is controllably deformable when subjected to mechanical loads in excess of a predetermined load. The method comprises steps of: (a) arranging at least one structural member in a predetermined orientation; and (b) introducing at least one energy-absorbing zone in a predetermined region of the at least one structural member. This, in turn, facilitates controlled deformation of the structural member when subjected to loads of lesser magnitude than are required to deform the remainder of the at least one structural member.

In a preferred embodiment, the step of introducing the at least one energy-absorbing zone in a predetermined region of the at least one structural member comprises the step of softening predetermined regions of the at least one structural member through localized heat treatment.

In another preferred embodiment, the step of introducing at least one energy absorbing zone in a predetermined region of the at least one structural member comprises the step of mechanically pre-deforming predetermined regions of the at least one structural member in a desired, predetermined orientation.

In yet another preferred embodiment, the step of introducing at least one energy absorbing zone in a predetermined region of the at least one structural member further comprises the steps of: (a) softening the predetermined region of the at least one structural member through localized heat treatment; (b)

mechanically pre-deforming the softened regions of the at least one structural member in a predetermined orientation; and (c) hardening a portion of the predetermined region of the at least one structural member toward its pre-softened hardness.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view of a frame structure comprised of a plurality of structural members;

Fig. 2 is a perspective view of an embodiment of a specially treated structural member having an energy absorbing zone; and

Fig. 3 is a perspective view of an embodiment of a specially treated structural member having a plurality of energy absorbing zones.

DETAILED DESCRIPTION OF THE DRAWINGS

While this invention is susceptible of embodiment in many different forms, there is shown in the drawings and described in detail herein several preferred embodiments with the understanding that the present disclosure is to be considered as an example of the principles of the invention, and is not intended to limit the invention to the illustrated embodiments.

Controllably deformable frame structure 20 is shown in Fig. 1 as including a plurality of structural members, such as structural members 22, 24 and 26, and controllable deformation means 57 (as shown in Figs. 2 an 3). As can be seen in Fig. 1, when the structural members are used, for example, as part of an automotive space frame, such structural member may comprise side members 22, cross members 24, and vertical members 26, among others. Controllably deformable frame structure 20 may also be comprised of more or fewer structural members than are shown in Fig. 1, and the structural members may be configured in any desired, predetermined orientation, which may be different from that shown in Fig. 1.

In the embodiment of Fig. 1, it is contemplated that at least a portion of the structural members include controllable deformation means 57 (Figs. 2 and 3), while other ones of the structural members omit such controllable deformation means. Indeed, as will be more fully explained and understood to those having ordinary skill in the art, operative and relative location of such controllable deformation means will serve to enable controlled deformation of the particular

frame structure when excessive impact is imparted upon the particular frame structure.

Fig. 2 illustrates a specially treated structural member 50 according to the invention. In such an embodiment, Structural member 50 comprises an elongated, hollow member of rectangular cross section, having a first end 51, a second end 52, and four side walls 53 through 56. Each side wall includes a respective end surface 53a through 56a, defining each side's thickness. Structural member 50 further includes controllable deformation means 57, which, as will be understood, comprises an "energy-absorbing" zone. Controllable deformation means 57 comprises a region which has been subjected to a retrogression heat treatment process. As will be explained, such a process enables a localized region (of the frame) to become softened and then rehardened toward its original hardness. Indeed, based upon the time of heating and cooling, structural characteristics of the region can be altered to, for example, result in a structure that is more malleable at the localized region as compared to the remainder of the structure. Additionally, as will also be explained, such localized regions can be machineably altered prior to hardening -- so as to, for example, enable structural indentations to be imparted into the structure toward facilitation of controlled deformation of the structure upon excessive impact.

As shown in Fig. 2, controllable deformation means 57 further comprises a plurality of indentations 58 having a desired, predetermined size, shape, and depth. Although indentations 58 are shown as oblong, they may be of other suitable shapes as well, such as, for example, square or circular. The number, shape, size,

and orientation of the indentations relative to each other and to the overall dimensions of any side 53 through 56 of structural member 50 may be varied as required to provide the structural member 50 with the desired deformability characteristics. For example, Fig. 2 illustrates controllable deformation means 57 as comprising a uniform pattern of indentations 58 on each of side walls 53 through 56. In other embodiments, indentations 58 may be applied in a uniform or non-uniform pattern to any of, or all of, sides 53 through 56 of structural member 50.

As previously explained, controllable deformation means 57 may comprise specific regions wherein the structural member has been locally softened through the use of a retrogression heat treatment. The manner and extent of the heat treatment may be varied to achieve the desired deformability characteristics. In particular, the energy-absorbing characteristics of structural member may be established in a desired, predetermined manner by applying such a retrogression heat treatment in varying manners, including varying temperatures and durations, at various predetermined locations on any or all of the sides of the structural member.

Additionally, each structural member may comprise more than one energy-absorbing zone (controllably deformation means) 57. For example, in the embodiment illustrated in Fig. 3, structural member 50 has two separate energy-absorbing zones, each comprising a pattern of circular indentations. In such a structural member, it is possible for one or more of such zones to be comprised of

a pattern of indentations, while one or more other such zones are comprised of specially heat treated regions.

Although not required, in a preferred embodiment, structural member 50 comprises a 6000-series aluminum alloy formed by an extrusion process. However, it is also contemplated that various other suitable materials and other commercial processes, such as stamping be used. Furthermore, although structural member 50 is illustrated as being hollow, it is likewise contemplated that the structural member be of solid or varying cross section, as well as having a plethora of different overall geometries.

In operation, controllably deformable frame structure 20, may be subjected to an impact load that exceeds a desired, predetermined value. Such an impact load may place a load on one or more of the treated structural members 50. When subjected to a load which exceeds a predetermined value, energy-absorbing zone 57 (controllable deformation means) will begin to deform at a load of lesser magnitude than is required to deform the other portions of the structural member. Each energy absorbing zone 57 associated with each structural member may be designed to deform in a desired, predetermined rate and in a desired, predetermined orientation -- regardless of the point, magnitude, or direction of impact. In frame structures comprising automobile frames, for example, a frame structure may be designed to deform, in response to a predetermined range of impact load, in a manner that absorbs an optimal amount of collision energy, in order to protect the passengers and critical components of a vehicle, such as a fuel tank.

The process for fabricating a controllably deformable frame structure 20 comprises first forming a structural member (such as structural members 22, 24, 26 and 50) in a conventional manner, as would be known to one skilled in the art. For example, a typical structural member may be formed by extruding an elongated, hollow member of rectangular cross section according to known mill processes, and then annealing the extruded member to a desired, predetermined hardness. Alternatively, the structural member may be initially formed as a solid extrusion, a stamping, a combination of extrusions and/or stampings, or by other suitable means.

Next, energy-absorbing zones 57 are added to the extruded member. As will be understood, such energy absorbing zones can be imparted during or after extrusion.

Energy-absorbing zones 57 may be created in the form of indentations stamped into any or all of the side walls in selected predetermined regions of the structural member. Preferably, energy-absorbing zones 57 may be created by locally softening, or making more malleable, the material comprising the structural members in selected predetermined regions of the structural member. In a preferred embodiment, selected predetermined regions of structural member 50 may be locally softened to facilitate the stamping of indentations; indentations may then be stamped into any or all of the side walls, and finally, the softened region may then be hardened, as desired, towards its pre-softened hardness.

For those embodiments wherein predetermined regions of the structural member(s) are locally softened, it is contemplated such softening be effected by

using a retrogression heat treatment as disclosed in U.S. Pat. No. 4,766,664 issued to Joseph C. Benedyk, for a Process for Formation of High Strength Ladder Structures and U.S. Pat. No. 5,458,393, issued to Joseph C. Benedyk, for a Space Frame Apparatus and Process for the Manufacture of Same, both of which are incorporated herein by reference. Using this process, an induction coil is placed in operable contact with the specific area to be heated and, in turn, softened, with only minimal heat being conducted to areas adjacent to the predetermined regions.

A controllably deformable frame structure (such as frame structure 20) may then be assembled from one or more structural members, using any suitable process. At least a portion of the individual structural members are contemplated to comprise structural members having energy-absorbing zones. One such acceptable process for assembling the frame structure, when multiple frame structures are used, is described in the previously identified patents to Joseph C. Benedyk. Of course, other processes known in the art, such as the use of mechanical nodes or welding, may also be used to assemble multiple frame structures.

If desired, energy absorbing zones 57 may be added to the individual structural members comprising the frame structure after the individual structural members have been assembled into the frame structure. It may be desirable to do so to avoid subjecting energy absorbing zones 57 to undesired loads which may be encountered during assembly of the frame structure.

The frame structure treated with the particular described controllable deformation means greatly facilitates controlled energy absorbtion through

deformation of the frame structure upon impact of predetermined loads. Additionally, as will be readily recognized, by isolating, or preselecting regions to be heated by the retrogression heat treatment, not only will controlled deformation occur upon impacts at predetermined loads, but such deformation will likewise occur in a controlled deformation pattern.

The foregoing description and drawings are merely to explain and illustrate the invention and the invention is not limited thereto except insofar as the appended claims are so limited, as those skilled in the art who have the disclosure before them will be able to make modifications and variations therein without departing from the scope of the invention.

CLAIMS

1. A controllably deformable frame structure comprising:

- at least one structural member; and
- means for controllably deforming the frame structure, the controllable deforming means comprising at least one energy-absorbing zone operably disposed within at least one of the at least one structural member, to, in turn, controllably deform when subjected to loads of lesser magnitude than required to plastically deform the remainder of the at least one structural member.

2. The invention according to claim 1 wherein the at least one structural member comprises a metal material.

3. The invention according to claim 2 wherein the metal material includes aluminum.

4. The invention according to claim 1 wherein the at least one structural member comprises an extruded member.

5. The invention according to claim 1 wherein the at least one structural member comprises a stamped member.

6. The invention according to claim 1 wherein the frame structure comprises at least a portion of an automobile frame structure.

7. The invention according to claim 6 wherein the at least a portion of an automobile frame structure comprises a bumper support.

8. The invention according to claim 1 wherein the at least one energy absorbing zone of the at least one structural member comprises a locally heat treated region.

9. The invention according to claim 1 wherein the at least one energy absorbing zone of the at least one structural members comprises at least one of a mechanically pre-deformed region, and a locally heat treated region.

10. The invention according to claim 1 wherein the at least one energy absorbing zone of the at least one structural member comprises a region which has been locally heat treated, mechanically pre-deformed, and rehardened.

11. A method for manufacturing a frame structure which is controllably deformable when subjected to mechanical loads in excess of a predetermined load, the method comprising the steps of:

- arranging at least one structural member in a predetermined orientation; and
- introducing at least one energy-absorbing zone in a predetermined region of the at least one structural member, to in turn, facilitate controlled deformation when subjected to loads of lesser magnitude than are required to deform the remainder of the at least one structural member.

12. The method according to claim 11 wherein the step of introducing the at least one energy-absorbing zone in a predetermined region of the at least one structural member comprises the step of softening predetermined regions of the at least one structural member through localized heat treatment.

13. The method according to claim 11 wherein the step of introducing at least one energy absorbing zone in a predetermined region of the at least one structural member comprises the step of mechanically pre-deforming predetermined regions of the at least one structural member in a desired, predetermined orientation.

14. The method according to claim 11 wherein the step of introducing at least one energy absorbing zone in a predetermined region of the at least one structural member further comprises the steps of:

- softening the predetermined region of the at least one structural member through localized heat treatment;
- mechanically pre-deforming the softened regions of the at least one structural member in a predetermined orientation; and
- hardening a portion of the predetermined region of the at least one structural member toward its pre-softened hardness.

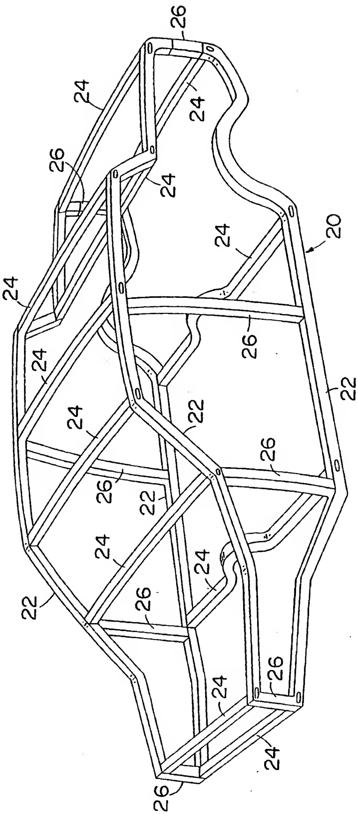

FIG. I

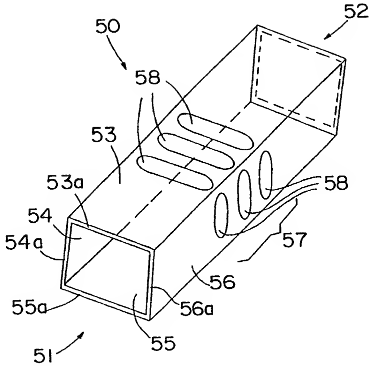

FIG. 2

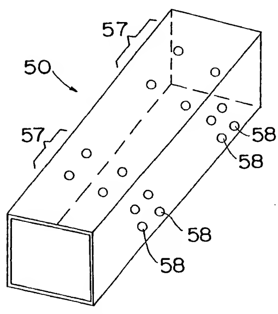

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/04233

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B62D 21/15
US CL :296/189; 280/784
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 296/189, 188, 205; 280/784

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 4,684,151 A (DREWEK) 04 August 1987, figure 2.	1-7, 11 --- 8-10, 12-14
X --- Y	US 4,702,515 A (KATO et al.) 27 October 1987, figure 1.	1-7, 11 --- 8-10, 12-14

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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Date of the actual completion of the international search

27 APRIL 1998

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/04233

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 5,431,445 A (WHEATLEY) 11 July 1995, figure 1.	1-7, 11 --- 8-10, 12-14
Y	US 5,458,393 A (BENEDYK) 17 October 1995, abstract.	8-10, 12-14
X --- Y	JP 4-39172 A (MORI) 10 February 1992, figure 1.	1-7, 11 --- 8-10, 12-14
X --- Y	JP 55-136660 A (SUZUKI) 24 October 1980, figure 3.	1-7, 11 --- 8-10, 12-14

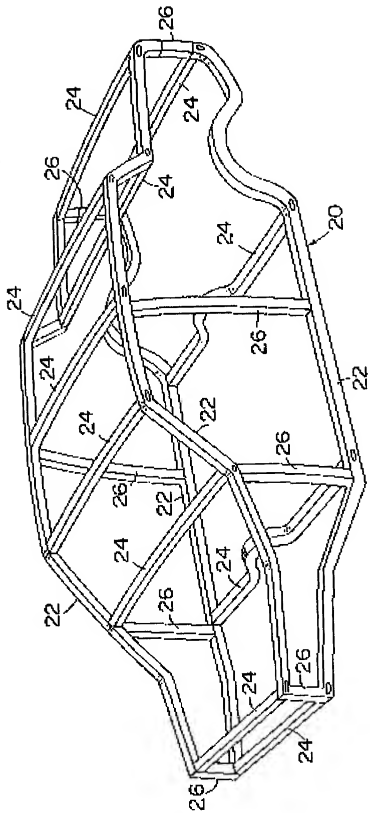
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FIG. I

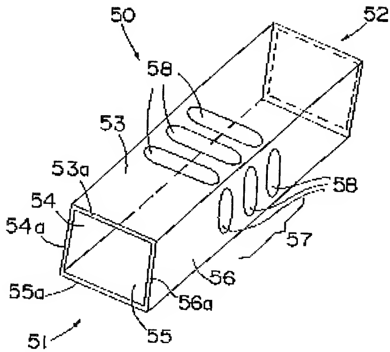

FIG. 2

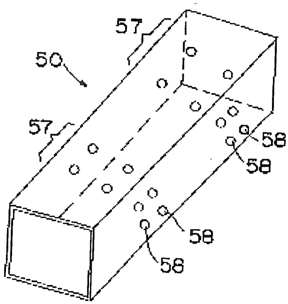

FIG. 3